Appendix F

Supplemental Fish Information

Appendix F
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F.1 Introduction

This appendix provides supplemental information to Section 3.5, “Fish.”

F.2 Life Histories

This section describes the key environmental requirements for each life stage of the selected species.

F.2.1 Chinook Salmon

After 2–5 years in the ocean, adult Chinook salmon leave the ocean and migrate upstream in the Sacramento and San Joaquin Rivers. The names of the Chinook salmon runs (i.e., fall, late fall, winter, and spring) reflect the variability in timing of the adult life stage (Table F-1). Spawning occurs in the cool reaches of Central Valley rivers that are downstream of the terminal dams and in tributary streams. After the eggs hatch, juvenile Chinook salmon may remain in fresh water for 3–14 months.

Historical records indicate that adult spring-run Chinook salmon enter the mainstem Sacramento River in March, and continue to their spawning streams where they hold until September in deep cold pools (Table F-1). Spring-run Chinook salmon are sexually immature during their spawning migration. Spawning occurs in gravel beds in late August through October, and emergence begins in December. Spring-run Chinook salmon migrate downstream as young-of-year or yearling juveniles. Young-of-year juveniles move downstream between February and June, and yearling juveniles migrate from October to March, with peak migration in November (Cramer and Associates 1997).

Adult fall-/late fall–run Chinook salmon enter the Sacramento and San Joaquin River systems from July through February and spawn from October through March (Table F-1). Optimal water temperature for egg incubation is 44 to 54°F (Rich 1997). Newly emerged fry remain in shallow, lower-velocity edgewaters

(California Department of Fish and Game 1998). Juveniles migrate to the ocean from October to June (Table F-1).

Adult winter-run Chinook salmon leave the ocean and migrate through the Sacramento–San Joaquin River Delta (Delta) into the Sacramento River from December through July. Adults migrate upstream past Red Bluff Diversion Dam (RBDD) on the Sacramento River from mid-December through July, and most of the spawning population has passed RBDD by late June. Spawning takes place from mid-April through August, and incubation continues through October. (Table F-1.) The primary spawning grounds in the Sacramento River are above RBDD. Juvenile winter-run Chinook salmon rear and migrate in the Sacramento River from July through March (Hallock and Fisher 1985; Smith pers. comm.). Juveniles move downstream in the Sacramento River from August through October and possibly November, rearing as they move downstream. Juveniles have been observed in the Delta during October through December, especially during high Sacramento River discharge in response to fall and early-winter storms. Winter-run salmon juveniles migrate through the Delta to the ocean from December through as late as May (Stevens 1989).

During spawning, the female digs a redd (a nest in clean gravel) and deposits eggs. A male fertilizes the eggs during the creation of the redd. Optimal water temperature for egg incubation is 44 to 54°F (Rich 1997). Newly emerged fry remain in shallow, lower-velocity edgewaters (California Department of Fish and Game 1998). Juveniles rear in their natal streams, the mainstem of the Sacramento River, and in the Delta.

Cover, space, and food are necessary components for Chinook salmon rearing habitat. Suitable habitat includes areas with instream and overhead cover in the form of cobbles, rocks, undercut banks, downed trees, and large, overhanging tree branches. The organic materials forming fish cover also provide sources of food, in the form of both aquatic and terrestrial insects.

Juvenile Chinook salmon move downstream in response to many factors, including inherited behavior, habitat availability, flow, competition for space and food, and water temperature. The number of juveniles that move and the timing of movement are highly variable. Storm events and the resulting high flows appear to trigger movement of substantial numbers of juvenile Chinook salmon to downstream habitats. In general, juvenile abundance in the Delta appears to be higher in response to increased flow (U.S. Fish and Wildlife Service 1993).

F.2.2 Steelhead

Steelhead have one of the most complex life histories of any salmonid species. Steelhead are anadromous, but some individuals may complete their life cycle within a given river reach. Freshwater residents typically are referred to as rainbow trout, while anadromous individuals are called steelhead (National Marine Fisheries Service 1996a).

Table F-1. Life Stage Timing and Distribution of Selected Species

	Distribution	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Late Fall–Run Chinook Salmon													
Adult Migration	SF Bay to Upper Sacramento River and Tributaries, Mokelumne River, and San Joaquin River Tributaries												
Spawning	Upper Sacramento River and Tributaries, Mokelumne River and San Joaquin River Tributaries												
Egg Incubation	Upper Sacramento River and Tributaries, Mokelumne River and San Joaquin River Tributaries												
Juvenile Rearing (Natal Stream)	Upper Sacramento River and Tributaries, Mokelumne River and San Joaquin River Tributaries												
Juvenile Movement and Rearing	Upper Sacramento River and Tributaries, Mokelumne River and San Joaquin River Tributaries												
Fall-Run Chinook Salmon													
Adult Migration and Holding	SF Bay to Upper Sacramento River and Tributaries												
Spawning[1]	Upper Sacramento River and Tributaries												
Egg Incubation[1]	Upper Sacramento River and Tributaries												
Juvenile Rearing (Natal Stream)	Upper Sacramento River and Tributaries												
Juvenile Movement	Upper Sacramento River and Tributaries to SF Bay												

	Distribution	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Spring-Run Chinook Salmon													
Adult Migration and Holding	SF Bay to Upper Sacramento River and Tributaries			■	■	■	■	■	■	■			
Spawning	Upper Sacramento River and Tributaries								■	■	■		
Egg Incubation	Upper Sacramento River and Tributaries								■	■	■	■	■
Juvenile Rearing (Natal Stream)	Upper Sacramento River and Tributaries	■	■	■	■	■	■	■	■	■	■	■	■
Juvenile Movement	Upper Sacramento River and Tributaries to SF Bay	■	■	■	■	■					■	■	■
Winter-Run Chinook Salmon													
Adult Migration and Holding	SF Bay to Upper Sacramento River	■	■	■	■	■	■	█					█
Spawning	Upper Sacramento River				■	■	■	■	█				
Egg Incubation	Upper Sacramento River				█	■	■	■	■	■	█		
Juvenile Rearing (Natal Stream)	Upper Sacramento River to SF Bay	■	■	■	■			■	■	■	■	■	■
Juvenile Movement and Rearing	Upper Sacramento River to SF Bay	■	■	■	■	█					■	■	■

	Distribution	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Steelhead													
Adult Migration	SF Bay to Upper Sacramento River and Tributaries												
Spawning	Upper Sacramento River and Tributaries												
Egg Incubation	Upper Sacramento River and Tributaries												
Juvenile Rearing	Upper Sacramento River and Tributaries to SF Bay												
Juvenile Movement	Upper Sacramento River and Tributaries to SF Bay												
Southern Oregon/Northern California Coasts Coho Salmon													
Adult Migration	Trinity River												
Juvenile Rearing	Trinity River												
Juvenile Movement	Trinity River												
Splittail													
Adult Migration	Suisun Marsh, Upper Delta, Yolo and Sutter Bypasses, Sacramento River and San Joaquin River												
Spawning	Suisun Marsh, Upper Delta, Yolo and Sutter Bypasses, Lower Sacramento and San Joaquin Rivers												
Larval and Early Juvenile Rearing and Movement	Suisun Marsh, Upper Delta, Yolo Bypass, Sutter Bypass, Lower Sacramento and San Joaquin Rivers												

Table F-1. Continued

	Distribution	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult and Juvenile Rearing	Delta, Suisun Bay												
Delta Smelt													
Adult Migration	Delta												
Spawning	Delta, Suisun Marsh												
Larval and Early Juvenile Rearing	Delta, Suisun Marsh												
Estuarine Rearing: Juveniles and Adults	Lower Delta, Suisun Bay												

Low probability of occurrence, not included in the assessment of the project effect.

Primary occurrence included in the assessment of project effects.

Notes:

[1] Spawning and incubation occurs from October to February in the Feather, American, and Mokelumne Rivers

Sources: Wang and Brown 1993; U.S. Fish and Wildlife Service 1996; McEwan 2001; Moyle 2002; Hallock 1989.

Historical records indicate that adult steelhead enter the mainstem Sacramento River in July, peak in abundance in September and October, and continue migrating through February or March (Table F-1) (McEwan and Jackson 1996; Hallock 1989). Most steelhead spawn from December through April (Table F-1), with most spawning occurring from January through March. Unlike Chinook salmon, some steelhead may survive to spawn more than one time, returning to the ocean between spawning migrations.

The female digs a redd in which she deposits her eggs. The duration of egg incubation in the gravel is determined by water temperature, varying from approximately 19 days at an average water temperature of 60°F to approximately 80 days at an average temperature of 40°F. Steelhead fry usually emerge from the gravel 2 to 8 weeks after hatching (Barnhart 1986; Reynolds et al. 1993). Newly emerged steelhead fry move to shallow, protected areas along streambanks and move to faster, deeper areas of the river as they grow. Most juveniles occupy riffles in their first year of life and some of the larger steelhead live in deep fast runs or in pools. Juvenile steelhead feed on a variety of aquatic and terrestrial insects and other small invertebrates.

Juvenile migration to the ocean generally occurs from December through August (Table F-1). Most Sacramento River steelhead migrate in spring and early summer (Reynolds et al. 1993). Sacramento River steelhead generally migrate as 1-year-olds at a length of 6 to 8 inches (Barnhart 1986; Reynolds et al. 1993). Although steelhead have been collected in most months at the state and federal pumping plants in the Delta, the peak numbers salvaged at these facilities occur in March and April in most years.

After 2–3 years of ocean residence, adult steelhead return to their natal stream to spawn as 3- or 4-year-olds (National Marine Fisheries Service 1998).

F.2.3 Coho Salmon

Coho salmon are anadromous fish that migrate as adults into the Trinity River to spawn. Adult migration occurs from mid-September through December, and spawning typically takes place between November and January (Table F-1) (Moyle 2002). Coho salmon adults spawn in waters with velocities of 0.25–0.31 meter per second (m/sec) and depths of 0.3–0.31 meter (Hampton 1988). Redds are formed near the heads of riffles in medium-to-small gravel that provide good flow and aeration. Spawning occurs over about a week. Embryos hatch after 8–12 weeks depending on the water temperature, and larvae remain in the gravel for 4–10 weeks until their yolk sacs are absorbed (Leidy and Leidy 1984). After hatching, the juveniles move to shallow water along the stream margins (Moyle 2002).

Habitat includes backwaters, side channels, and stream margins adjacent to large, slow runs or pools. Coho salmon will shift their habitat use depending on the season, but use mostly deep pools with overhead cover in the summer (Moyle

2002). Cover is the most important rearing habitat feature; coho salmon seek areas with overhanging vegetation (e.g., brush and logs) and thick clusters of aquatic vegetation (Hampton 1988). Optimal growth temperature ranges from 11.7 to 13.9°C, and they prefer velocities of 0.09 to 0.46 m/sec (Moyle 2002). Juveniles are absent from tributaries that reach temperatures warmer than 17.8°C for more than a week.

Juvenile coho salmon rear in tributary streams for up to 15 months before migrating to the ocean. Downstream migration occurs from March through May, with peak occurrence in late April through mid-May when conditions are favorable (Table F-1) (Moyle 2002).

F.2.4 Delta Smelt

Estuarine rearing habitat for juvenile and adult delta smelt is typically found in the waters of the lower Delta and Suisun Bay where salinity is between 2 and 7 parts per thousand (ppt). Delta smelt tolerate 0 ppt to 19 ppt salinity. They commonly occupy open shallow waters but also occur in the main channel in the region where fresh water and brackish water mix. The zone may be hydraulically conducive to their ability to maintain position and metabolic efficiency (Moyle 2002).

Adult delta smelt begin spawning migration into the upper Delta in December or January (Table F-1). Migration may continue over several months. Spawning occurs between January and July, with peak spawning during April through mid-May (Moyle 2002). Spawning occurs along the channel edges in the upper Delta, including the Sacramento River above Rio Vista, Cache Slough, Lindsey Slough, and Barker Slough. Spawning has been observed in the Sacramento River up to Garcia Bend during drought conditions, possibly attributable to adult movement farther inland in response to saltwater intrusion (Wang and Brown 1993). Eggs are broadcast over the bottom, where they attach to firm substrate, woody material, and vegetation. Hatching takes approximately 9 to 13 days, and larvae begin feeding 4 to 5 days later. Newly hatched larvae contain a large oil globule and are semi-buoyant. Larval smelt feed on rotifers and other zooplankton. As their fins and swim bladder develop, they move higher into the water column. Larvae and juveniles gradually move downstream toward rearing habitat in the estuarine mixing zone (Wang 1986).

F.2.5 Splittail

Adult splittail migrate from Suisun Bay and the Delta to upstream spawning habitat during December through March (Table F-1). Surveys indicate that the Yolo and Sutter Bypasses provide important spawning habitat (Sommer et al. 1997). Both male and female splittail become sexually mature by their second winter at about 10 centimeters (cm) in length. Female splittail are capable of producing more than 100,000 eggs per year (Daniels and Moyle 1983; Moyle et al. 1989). Adhesive eggs are deposited over flooded terrestrial or aquatic vegetation when water temperature is between 48°F and 68°F (Moyle 2002; Wang 1986). Splittail spawn in late April and May in Suisun Marsh and between early March and May in the upper Delta and lower reaches and flood bypasses of the Sacramento and San Joaquin Rivers (Moyle et al. 1989). Spawning has been observed to occur as early as January and may continue through early July (Table F-1) (Wang 1986; Moyle 2002).

The diet of adults and juveniles includes decayed organic material; earthworms, clams, insect larvae, and other invertebrates; and fish. The mysid *Neomysis mercedis* is a primary prey species, although decayed organic material constitutes a larger percentage of the stomach contents (Daniels and Moyle 1983).

Larval splittail are commonly found in shallow, vegetated areas near spawning habitat. Larvae eventually move into deeper and more open-water habitat as they grow and become juveniles. During late winter and spring, young-of-year juvenile splittail (i.e., production from spawning in the current year) are found in sloughs, rivers, and Delta channels near spawning habitat (Table F-1). Juvenile splittail gradually move from shallow, nearshore areas to deeper, open water habitat of Suisun and San Pablo Bays (Wang 1986). In areas upstream of the Delta, juvenile splittail can be present in the flood bypasses when these areas are inundated during the winter and spring (Jones & Stokes 1993; Sommer et al. 1997).

F.2.6 Striped Bass

Striped bass are nonnative to the Sacramento–San Joaquin River system. They spend most of their lives in San Pablo and San Francisco Bays and move upstream to spawn. Spawning peaks in May and June, and its location depends on water temperature, flow, and salinity. Spawning occurs in the Delta and in the Sacramento River during the spring. Striped bass are open-water spawners, and their eggs must remain suspended in the current to prevent mortality. Embryos and larvae in the Sacramento River are carried into the Delta and Suisun Bay where rearing appears to be best (Moyle 2002). Larval and juvenile striped bass feed mainly on invertebrates, including copepods and opossum shrimp. Fish become a more important part of their diet as they grow in size (Moyle 2002). Young striped bass tend to accumulate in or just upstream of the estuary's freshwater/saltwater mixing zone, and this region is critical nursery habitat (California Department of Fish and Game 1991b). Striped bass reach maturity at 4 to 6 years of age. Adult striped bass are open-water predators and opportunistic feeders at the top of the aquatic food web (Bureau of Reclamation 1996).

Striped bass populations in the Delta have been in steady decline since the late 1970s. A changing atmospheric-oceanic climate may be at the root of this decline. The decline in striped bass abundance may be related to increasing ocean temperatures (Bennett and Howard 1999).

F.2.7 Other Species

In addition to the species discussed above, Central Valley rivers and reservoirs support many native and nonnative fish species (Table F-2). In general, native species, such as Sacramento pikeminnow, hardhead, Sacramento sucker, and California roach spawn early in the spring. Most native fishes do not guard the young as a result of evolving in an environment relatively low in potential predators. Native fishes are also adapted to rear in flooded areas that provide abundant cover and abundant prey (Moyle 2002).

Longfin smelt are anadromous, euryhaline and nektonic. Adults and juveniles are found in estuaries and can tolerate salinities from 0 ppt to pure seawater. After the early juvenile stage, they prefer salinities in the 15–30 ppt range (Moyle 2002). Longfin smelt are rarely found upstream of Rio Vista or Medford Island in the Delta and, except during spawning, concentrate in Suisun, San Pablo, and north San Francisco Bays (Moyle 2002).

Adult longfin smelt move upstream and spawn in fresh water as early as November and extend into June (Moyle 2002). Spawning occurs below Medford Island in the San Joaquin River and below Rio Vista on the Sacramento River. Embryos hatch in 40 days at 7°C and are buoyant. They move into the upper part of the water column and downstream into the estuary. High outflows may facilitate transport of larvae into Suisun and San Pablo Bays. In low outflow years, larvae move into the western Delta and Suisun Bay. Higher outflows are reflected positively in juvenile survival and adult abundance. Rearing habitat is in Suisun and San Pablo Bays because juveniles require brackish water in the 2–18 ppt range.

Green sturgeon are found in the Sacramento River. Spawning occurs in the mainstem Sacramento River and possibly in the lower Feather River. Juvenile fish have been collected in the Sacramento River, near Hamilton City, and in the Delta and San Francisco Bay. Adults and juveniles have been observed near RBDD in late winter and early spring. Green sturgeon are mostly marine fish, migrating into rivers to spawn. Early life stages may spend up to 2 years in fresh water (Moyle 2002). Juveniles inhabit the estuary until they are approximately 4 to 6 years old, when they migrate to the ocean (Kohlhorst et al. 1991). In the Sacramento River, green sturgeon are generally observed between late February and late July. Peak spawning occurs from mid-April to mid-June. Spawning substrate ranges from sand to bedrock in fast water deeper than 3 meters (Moyle 2002). The diet of adult green sturgeon seems to include mostly bottom invertebrates and small fish (Ganssle 1966). Juveniles in the Delta feed on opossum shrimp and amphipods (Radtke 1966).

With some exceptions, nonnative species, such as green sunfish, bluegill, white and channel catfish, and largemouth bass, spawn later in the spring and in the summer. Nonnative species are more successful in disturbed environments than native species. In general, they are adapted to warm, slow-moving, and nutrient-rich waters (Moyle 2002).

Table F-2. Central Valley Species Potentially Affected

Common Name—Origin	Scientific Name	Distribution
Lamprey (2 species)—native	*Lampetra* spp.	Central Valley rivers; Delta; San Francisco Bay estuary
Chinook salmon (winter-, spring-, fall-, and late fall–runs)—native	*Oncorhynchus tshawytscha*	Central Valley rivers; Delta; San Francisco Bay estuary
Chum salmon—rare	*Oncorhynchus keta*	Central Valley rivers; Delta and San Francisco Bay estuary
Kokanee—nonnative	*Oncorhynchus nerka*	Central Valley reservoirs
Steelhead/rainbow trout—native	*Oncorhynchus mykiss*	Central Valley rivers; Delta and San Francisco Bay estuary
Brown trout—nonnative	*Salmo trutta*	Central Valley reservoirs
White sturgeon—native	*Acipenser transmontanus*	Central Valley rivers; Delta; San Francisco Bay estuary
Green sturgeon—native	*Acipenser medirostris*	Central Valley rivers; Delta; San Francisco Bay estuary
Longfin smelt—native	*Spirinchus thaleichthys*	Delta and San Francisco Bay estuary
Delta smelt—native	*Hypomesus transpacificus*	Delta and San Francisco Bay estuary
Wakasagi—nonnative	*Hypomesus nipponensis*	Central Valley rivers and reservoirs; Delta
Sacramento sucker—native	*Catostomus occidentalis*	Central Valley rivers; Delta
Sacramento pikeminnow—native	*Ptychocheilus grandis*	Central Valley rivers; Delta
Splittail—native	*Pogonichthys macrolepidotus*	Central Valley rivers; Delta and San Francisco Bay estuary
Sacramento blackfish—native	*Orthodon microlepidotus*	Central Valley rivers; Delta
Hardhead—native	*Mylopharodon conocephalus*	Central Valley rivers; Delta
Speckled dace—native	*Rhinichthys osculus*	Sacramento River and tributaries
California roach—native	*Lavinia symmetricus*	Central Valley Rivers
Hitch—native	*Lavina exilicauda*	Central Valley rivers; Delta
Golden shiner—nonnative	*Notemigonus crysoleucas*	Central Valley rivers and reservoirs; Delta
Fathead minnow—nonnative	*Pimephales promelas*	Central Valley rivers and reservoirs; Delta
Goldfish—nonnative	*Carassius auratus*	Central Valley rivers and reservoirs; Delta
Carp—nonnative	*Cyprinus carpio*	Central Valley rivers and reservoirs; Delta
Threadfin shad—nonnative	*Dorosoma petenense*	Central Valley rivers and reservoirs; Delta
American shad—nonnative	*Alosa sapidissima*	Central Valley rivers; Delta; San Francisco Bay estuary
Black bullhead—nonnative	*Ictalurus melas*	Central Valley rivers and reservoirs; Delta
Brown bullhead—nonnative	*Ictalurus nebulosus*	Central Valley rivers and reservoirs; Delta
White catfish—nonnative	*Ictalurus catus*	Central Valley rivers; Delta

Table F-2. Continued

Common Name—Origin	Scientific Name	Distribution
Channel catfish—nonnative	*Ictalurus punctatus*	Central Valley rivers and reservoirs; Delta
Mosquito fish—nonnative	*Gambusia affinis*	Central Valley rivers and reservoirs; Delta
Inland silverside—nonnative	*Menidia audena*	Central Valley rivers; Delta
Threespine stickleback—native	*Gasterosteus aculaetus*	Central Valley rivers; Delta; San Francisco Bay estuary
Striped bass—nonnative	*Morone saxatilis*	Central Valley rivers and reservoirs; Delta; San Francisco Bay estuary
Bluegill—nonnative	*Lepomis macrochirus*	Central Valley rivers and reservoirs; Delta
Green sunfish—nonnative	*Lepomis cyanellus*	Central Valley rivers and reservoirs; Delta
Redear sunfish—nonnative	*Lepomis microlophus*	Central Valley rivers and reservoirs; Delta
Warmouth—nonnative	*Lepomis gulosus*	Central Valley rivers and reservoirs; Delta
White crappie—nonnative	*Pomoxis annularis*	Central Valley rivers and reservoirs; Delta
Black crappie—nonnative	*Pomoxis nigromaculatus*	Central Valley rivers and reservoirs; Delta
Largemouth bass—nonnative	*Micropterus salmoides*	Central Valley rivers and reservoirs; Delta
Redeye Bass—nonnative	*Micropterus coosae*	Central Valley rivers and reservoirs
Spotted bass—nonnative	*Micropterus punctulatus*	Central Valley rivers and reservoirs; Delta
Small mouth bass—nonnative	*Micropterus dolomieui*	Central Valley rivers and reservoirs; Delta
Bigscale logperch—nonnative	*Percina macrolepida*	Central Valley rivers; Delta
Yellowfin goby—nonnative	*Acanthogobius flavimanus*	Delta and San Francisco Bay estuary
Chameleon goby—nonnative	*Tridentiger trigonocephalus*	Delta and San Francisco Bay estuary
Prickly sculpin—native	*Cottus asper*	Central Valley rivers
Tule perch—native	*Hysterocarpus traskii*	Central Valley rivers; Delta

Shasta, Lewiston, Oroville, and Folsom Reservoirs support coldwater and warmwater fisheries that are composed primarily of nonnative fishes. Coldwater species include rainbow trout, kokanee, and brown trout. Warmwater species include largemouth bass, smallmouth bass and other sunfish, channel catfish and bullheads, and common carp. The exact species composition of each reservoir varies according to different species introductions and hatchery supplementation (Moyle 2002). The reservoirs are relatively artificial ecosystems that rarely meet all the needs of the species present. Factors such as water-level fluctuation, limited cover and spawning habitat, and inadequate forage base may affect the reproductive success of reservoir species and the capacity for supporting sustainable populations.

American shad are also a nonnative species. They are present in the Sacramento River up to RBDD and in the lower reaches of the American, Feather and Yuba Rivers. American shad occur in the San Francisco estuary after migrating from the ocean in the fall. They move into fresh water from March to May where they spawn. American shad spawn in upstream river reaches at temperatures from 63°F to 75°F, usually in May and June (Moyle 2002). Similar to striped bass eggs, shad eggs stay suspended in the water and gradually drift downstream. In the Sacramento River basin, the main summer rearing areas are the lower Feather River, the Sacramento River from Colusa to the north Delta, and to some extent the south Delta. Juvenile shad move to the ocean from September to November, although juvenile migration under high outflow conditions may begin in June.

F.3 Factors That Affect Abundance of Fish Species

Information relating abundance with environmental conditions is most available for listed species, especially Chinook salmon. The following section focuses on factors that have potentially affected the abundance of listed species in the Central Valley. Although not all species are discussed, many of the factors affecting the listed species have also affected the abundance of other native and nonnative species.

F.3.1 Spawning Habitat Area

Spawning habitat area may limit the production of juveniles and subsequent adult abundance of some species. Spawning habitat area for fall-/late fall–run Chinook salmon, which compose more than 90% of the Chinook salmon returning to the Central Valley streams, has been identified as limiting their population abundance. Spawning habitat area has not been identified as a limiting factor for the less-abundant winter-run and spring-run Chinook salmon (National Marine Fisheries Service 1996b; U.S. Fish and Wildlife Service 1996), although habitat may be limiting in some streams (e.g., Butte Creek) during years of high adult abundance.

Spawning habitat area is defined by a number of factors, such as gravel size and quality and water depth and velocity. Although maximum usable gravel size depends on fish size, a number of studies have determined that Chinook salmon require gravel ranging from approximately 0.3 cm (0.1 inch) to 15 cm (5.9 inches) in diameter (Raleigh et al. 1986). Steelhead prefer substrate no larger than 10 cm (3.9 inches) (Bjornn and Reiser 1991). Water depth criteria for spawning vary widely, and there is little agreement among studies about the minimum and maximum values for depth (Healey 1991). Salmonids spawn in water depths that range from a few inches to several feet. A minimum depth of 0.8 foot for Chinook salmon and steelhead spawning has been widely used in the literature and is within the range observed in some Central Valley rivers (California Department of Fish and Game 1991a). In general, water should be at least deep enough to cover the adult fish during spawning. Minimum water depth for steelhead spawning has been observed to be enough to cover the fish (Bjornn and Reiser 1991). Many fish spawn in deeper water. Velocity that supports spawning ranges from 0.8 feet per second (fps) to 3.8 fps (U.S. Fish and Wildlife Service 1994).

Delta smelt spawn in fresh water at low tide on aquatic plants, submerged and inshore plants, and over sandy and hard bottom substrates of sloughs and shallow edges of channels in the upper Delta and Sacramento River above Rio Vista (Wang 1986; Moyle 2002). Spawning habitat area has not been identified as a factor affecting delta smelt abundance (U.S. Fish and Wildlife Service 1996), but little is known about specific spawning areas and requirements within the Delta.

A lack of sufficient seasonally flooded vegetation may limit splittail spawning success (Young and Cech 1996; Sommer et al. 1997). Splittail spawn over flooded vegetation and debris on floodplains that are inundated by high flow from February to early July in the Sacramento River and San Joaquin River systems. The onset of spawning appears to be associated with rising water levels, increasing water temperature, and day length (Moyle 2002). The Sutter and Yolo Bypasses along the Sacramento River are important spawning habitat areas during high flow.

F.3.2 Rearing Habitat Area

Rearing habitat area may limit the production of juveniles and subsequent adult abundance of some species. USFWS (1996) has indicated rearing habitat area in Central Valley streams and rivers limits the abundance of juvenile fall-run and late fall–run Chinook salmon and juvenile steelhead. Rearing habitat for salmonids is defined by environmental conditions such as water temperature, dissolved oxygen (DO), turbidity, substrate, water velocity, water depth, and cover (Jackson 1992; Bjornn and Reiser 1991; Healey 1991). Chinook salmon also rear along the shallow vegetated edges of Delta channels (Grimaldo et al. 2000).

Environmental conditions and interactions between individuals, predators, competitors, and food sources determine habitat quantity and quality and the productivity of the stream (Bjornn and Reiser 1991). Everest and Chapman (1972) found juvenile Chinook salmon and steelhead of the same size using similar in-channel rearing area. Juvenile coho salmon use side-channel pools. Coho salmon prefer low velocity areas with good cover, especially in the winter (Bjornn and Reiser 1991).

Rearing area varies with flow. High flow increases the area available to juvenile Chinook salmon because they extensively use submerged terrestrial vegetation on the channel edge and the floodplain. Deeper inundation provides more overhead cover and protection from avian and terrestrial predators than shallow water (Everest and Chapman cited in Jackson 1992). In broad, low-gradient rivers, change in flow can greatly increase or decrease the lateral area available to juvenile Chinook salmon, particularly in riffles and shallow glides (Jackson 1992).

Rearing habitat for larval and early juvenile delta smelt encompasses the lower reaches of the Sacramento River below Isleton and the San Joaquin River below Mossdale. Estuarine rearing by juveniles and adults occurs in the lower Delta and Suisun Bay. USFWS (1996) has indicated that loss of rearing habitat area would adversely affect the abundance of larval and juvenile delta smelt. The area and quality of estuarine rearing habitat is assumed to be dependent on the downstream location of approximately 2 ppt salinity (Moyle et al. 1992). The condition where 2 ppt salinity is located in the Delta is assumed to provide less habitat area and lower quality habitat than the habitat provided by 2 ppt salinity located farther downstream in Suisun Bay. During years of average and high outflow, delta smelt may concentrate anywhere from the Sacramento River around Decker Island to Suisun Bay (Moyle 2002). This geographic distribution may not always be a function of outflow and 2 ppt isohaline position. Outflow and the position of the 2 ppt isohaline may account for only about 25% of the annual variation in abundance indices for delta smelt (California Department of Water Resources and Bureau of Reclamation 1994).

Rearing habitat has not been identified as a limiting factor in splittail population abundance, but as with spawning, a lack of sufficient seasonally flooded vegetation may limit population abundance and distribution (Young and Cech 1996). Rearing habitat for splittail encompasses the Delta, Suisun Bay, Suisun Marsh, the lower Napa River, the lower Petaluma River, and other parts of San Francisco Bay (Moyle 2002). In Suisun Marsh, splittail concentrate in the dead-end sloughs that have small streams feeding into them (Daniels and Moyle 1983; Moyle 2002). As splittail grow, salinity tolerance increases (Young and Cech 1996). Splittail are able to tolerate salinity concentrations as high as 29 ppt and as low as 0 ppt (Moyle 2002).

F.3.3 Migration Habitat Conditions

The Sacramento, Feather, Yuba, American, and Mokelumne Rivers and the Delta provide a migration pathway between freshwater and ocean habitats for adult and juvenile steelhead and all runs of Chinook salmon. The Trinity River provides a migration pathway for coho salmon, Chinook salmon, and steelhead.

Migration habitat conditions include streamflows that provide suitable water velocities and depths that provide successful passage. Flow in the Sacramento, Feather, Yuba, American, and Mokelumne Rivers and in the Delta provide the necessary depth, velocity, and water temperature. Within the Delta, the channel pathways affect migration of juvenile Chinook salmon. Juvenile Chinook salmon survival is lower for fish migrating through the central Delta (i.e., diverted into the Delta Cross Channel [DCC] and Georgiana Slough) than for fish continuing down the Sacramento River (Newman and Rice 1997). Similarly, juvenile Chinook salmon entering the Delta from the San Joaquin River appear to have higher survival if they remain in the San Joaquin River channel instead of moving into Old River and the south Delta (Brandes and McLain 2001).

Larval and early juvenile delta smelt are transported by currents that flow downstream into the upper end of the mixing zone of estuary where incoming saltwater mixes with outflowing fresh water (Moyle et al. 1992). Reduced flow may adversely affect transport of larvae and juveniles to rearing habitat.

Adult splittail gradually move upstream during the winter and spring months to spawn. Year class success of splittail is positively correlated with wet years, high Delta outflow, and floodplain inundation (Sommer et al. 1997; Moyle 2002). Low flow impedes access to floodplain areas that support rearing and spawning.

F.3.4 Water Temperature

Fish species have different responses to water temperature conditions depending on their physiological adaptations. Salmonids in general have evolved under conditions in which water temperatures need to be relatively cool. Delta smelt and splittail can tolerate warmer temperatures. In addition to species-specific thresholds, different life stages have different water temperature requirements. Eggs and larval fish are the most sensitive to warm water temperature.

Unsuitable water temperatures for adult salmonids such as Chinook salmon, steelhead, and coho salmon during upstream migration lead to delayed migration and potential lower reproduction. Elevated summer water temperatures in holding areas cause mortality of spring-run Chinook salmon (U.S. Fish and Wildlife Service 1996). Warm water temperature and low DO also increase egg and fry mortality. USFWS (1996) cited elevated water temperatures as limiting factors for fall- and late fall–run Chinook salmon.

Juvenile salmonid survival, growth, and vulnerability to disease are affected by water temperature. In addition, water temperature affects prey species abundance and predator occurrence and activity. Juvenile salmonids alter their behavior depending on water temperature, including movement to take advantage of local water temperature refugia (e.g., movement into stratified pools, shaded habitat, and subsurface flow) and to improve feeding efficiency (e.g., movement into riffles).

Water temperature in Central Valley rivers frequently exceeds the tolerance of Chinook salmon and steelhead life stages. Based on a literature review, conditions supporting adult Chinook salmon migration are assumed to deteriorate as temperature warms between 54ºF and 70ºF (Hallock 1970 as cited in McCullough 1999). For Chinook salmon eggs and larvae, survival during incubation is assumed to decline with increasing temperature between 54ºF and 61ºF. (Myrick and Cech 2001; Seymour 1956 cited in Alderice and Velsen 1978). For juvenile Chinook salmon, survival is assumed to decline as temperature warms from 64ºF to 75ºF (Myrick and Cech 2001; Rich 1987). Relative to rearing, Chinook salmon require cooler temperatures to complete the parr-smolt transformation and to maximize their saltwater survival. Successful smolt transformation is assumed to deteriorate at temperatures ranging from 63ºF to 73ºF (Marine 1997 cited in Myrick and Cech 2001; Baker et al. 1995).

For steelhead, successful adult migration and holding is assumed to deteriorate as water temperature warms between 52ºF and 70ºF. Adult steelhead appear to be much more sensitive to thermal extremes than are juveniles (National Marine Fisheries Service 1996a; McCullough 1999). Conditions supporting steelhead spawning and incubation are assumed to deteriorate as temperature warms between 52ºF and 59ºF (Myrick and Cech 2001). Juvenile rearing success is assumed to deteriorate at water temperatures ranging from 63ºF to 77ºF (Raleigh et al. 1984; Myrick and Cech 2001). Relative to rearing, smolt transformation requires cooler temperatures, and successful transformation occurs at temperatures ranging from 43ºF to 50ºF. Juvenile steelhead, however, have been captured at Chipps Island in June and July at water temperatures exceeding 68ºF (Nobriega and Cadrett 2001). Juvenile Chinook salmon have also been observed to migrate at water temperatures warmer than expected based on laboratory experimental results (Baker et al. 1995).

Delta smelt and splittail populations are adapted to water temperature conditions in the Delta. Delta smelt may spawn at temperatures as high as 72ºF (U.S. Fish and Wildlife Service 1996) and can rear and migrate at temperatures as warm as 82ºF (Swanson and Cech 1995). Splittail may withstand temperatures as warm as 91ºF but prefer temperatures between 66ºF and 75ºF (Young and Cech 1996).

F.3.5 Entrainment

All fish species are entrained to varying degrees by the State Water Project (SWP) and Central Valley Project (CVP) Delta export facilities and other diversions in the Delta and Central Valley rivers. Fish entrainment and subsequent mortality are a function of the size of the diversion, the location of the diversion, the behavior of the fish, and other factors such as fish screens, presence of predatory species, and water temperature. Low approach velocities are assumed to minimize stress and protect fish from entrainment.

Juvenile striped bass populations have steadily declined since the mid-1960s partially because of entrainment losses of eggs and young fish at water diversions (Foss and Miller 2001). The CVP and SWP fish facilities indicate entrainment of adult delta smelt during spawning migration from December through April (California Department of Water Resources and Bureau of Reclamation 1994). Juveniles are entrained primarily from April through June. Young-of-year splittail are entrained between April and August when fish are moving downstream into the estuary (Cech et al. 1979 as cited in Moyle 2002). Juvenile Chinook salmon are entrained in all months but primarily from November through June when juveniles are migrating downstream.

F.3.6 Contaminants

In the Sacramento and San Joaquin River basins, industrial and municipal discharge and agricultural runoff introduce contaminants into rivers and streams that ultimately flow into the Delta. Organophosphate insecticides such as carbofuran, chlorpyrifos, and diazinon are present throughout the Central Valley and are dispersed in agricultural and urban runoff. These contaminants enter rivers in winter runoff and enter the estuary in concentrations that can be toxic to invertebrates (CALFED Bay-Delta Program 2000). Because they accumulate in living organisms, they may become toxic to fish species, especially those life stages that remain in the system year-round and spend considerable time there during the early stages of development, such as Chinook salmon, steelhead, splittail, and delta smelt.

F.3.7 Predation

Nonnative species cause substantial predation mortality on native species. Studies at Clifton Court Forebay (CCF) estimated predator-related mortality of hatchery-reared fall-run Chinook salmon from about 60% to more than 95%. Although the predation contribution to mortality is uncertain, the estimated mortality suggests that striped bass and other predatory fish, primarily nonnative, pose a threat to juvenile Chinook salmon moving downstream, especially where the stream channel has been altered from natural conditions (California Department of Water Resources 1995). Turbulence after passing over dams and other structures may disorient juvenile Chinook salmon and steelhead, increasing their vulnerability to predators. Predators such as striped bass, largemouth bass, and catfish also prey on delta smelt and splittail (U.S. Fish and Wildlife Service 1996). However, the extent that these predators may affect delta smelt and splittail populations is unknown.

F.3.8 Food

Food availability and type affect survival of fish species. Species such as threadfin shad and wakasagi may affect delta smelt survival through competition for food. Introduction of nonnative food organisms may also have an effect on delta smelt and other species survival. Nonnative zooplankton species are more difficult for small smelt and striped bass to capture, increasing the likelihood of larval starvation (Moyle 2002). Splittail feed on opossum shrimp, which in turn feed on native copepods that have shown reduced abundance, potentially attributable to the introduction of nonnative zooplankton and the Asiatic clam *Potamorcorbula amurensis*. In addition, flow affects the abundance of food in rivers, the Delta, and Suisun Bay. In general, higher flows result in higher productivity, including the higher input of nutrients from channel margin and floodplain inundation and higher production resulting when low salinity occurs in the shallows of Suisun Bay. Higher productivity increases the availability of prey organisms for delta smelt and other fish species.

F.4 Environmental Consequences

F.4.1 Assessment Approach and Methods

The assessment of a species response to project actions begins with statements of the hypothetical relationships between changes in environmental correlates and the expected species response. The underlying principles, specific methods, and available scientific support are discussed. Additional supporting information relative to species occurrence, life history, biology and physiology, and factors that have affected the historical and current species abundance is provided in the preceding Affected Environment.

Breadth of the Assessment

Changes in water supply operations (i.e., Delta exports and inflows) potentially affect environmental conditions in the Sacramento River downstream of Keswick Dam, the American River downstream of Nimbus Dam, the Feather River downstream of the Thermalito Diversion Dam, the Trinity River downstream of Lewiston Reservoir, and Folsom, Oroville, Shasta, and Clair Engle Reservoirs. The potential changes in water supply operations, affecting river flows, reservoir operations, and diversions and exports, are simulated by CALSIM over a range of conditions represented by the 1922–1994 hydrology (Section 5.1, Water Supply). The 1922–1994 hydrologies include wet and dry conditions and provide an indication of operations effects over variable sequences of hydrologic year types. The assessment of the effects of changes in water supply operations on fish species relies primarily on the simulated hydrology (Table F-3).

This assessment focuses primarily on fish species listed under the federal Endangered Species Act (ESA) and California Endangered Species Act (CESA). Assessment methods have been developed to address effects on southern Oregon/northern California coasts coho salmon (i.e., Trinity River), Central Valley steelhead, Central Valley fall-/late fall–run Chinook salmon, Sacramento River winter-run Chinook salmon, Central Valley spring-run Chinook salmon, delta smelt, splittail, and striped bass (Table F-3). Assessment methods are generally life stage–specific.

Although not all fish species potentially affected are specifically included in the assessment, the response of the selected species to project actions provides an indication of the potential response by species with similar environmental needs. Where the analysis for the selected species does not capture the potential project effects on another species (e.g., reservoir species), specific effects on the other species are described.

The analysis of the fisheries impacts for the Intertie are based on a version of the CALSIM II and Bureau of Reclamation temperature modeling conducted in April 2003. CALSIM II was updated in June of 2004. This updated hydrologic output was used as the basis for analysis in the Water Supply and Delta Water Management, Delta Tidal Hydraulics, and Water Quality analyses. When the revised modeling was completed, the June 2004 CALSIM II output was compared to the results from the April 2003 output for the Intertie. At that time it was clear that the differences were so small that conclusions of the previous April 2003 CALSIM and water temperature analysis for fisheries would not change.

Analytical Tools and Measures of Species Response

This section describes the tools applied to assess the potential effects of the Intertie on fish and other aquatic species (Table F-3). Tools are identified for assessment of change in environmental correlates potentially affected by water supply operations that could cause a measurable species response (i.e., a measurable change in survival, growth, fecundity, and movement).

Environmental correlates are expressed as some measurement unit, including linear feet or acres of habitat, degrees Fahrenheit, feet per second, thousand acre feet, cubic feet per second, and number of particles entrained. Hypotheses of the species response to variation in environmental correlates are identified for applicable species' life stages (Table F-4) and are translated into equations or models that indicate the species response. The response of each species to change in environmental correlates is determined by the ecology and physiology of a species' life stage.

Measures of a species response to changes in environmental correlates ideally quantify predicted survival, growth, fecundity, and movement. Predicted survival and fecundity support the assessment of changes in a species' population abundance that facilitate the determination of impact significance.

Table F-3. Summary of Assessment Models and Tools by Environmental Correlate for Each Fish Species and Life Stage

Assessed Environmental Correlate	Simulated Environmental Condition	Models Used to Simulate Environmental Conditions	Analytical Tool	Species: Life Stage
Spawning Habitat Quantity	River Flow—Trinity River	CALSIM, Water years 1922–1994	Qualitative assessment of flow effects	Coho Salmon: spawning and incubation
	River Flow—Sacramento River at Keswick Dam, Colusa, and Verona	CALSIM, Water years 1922–1994	Flow-habitat relationship for salmon and steelhead; high flow assessment of floodplain inundation for splittail	Winter-run Chinook Salmon: spawning and incubation
				Spring-run Chinook Salmon: spawning and incubation
				Fall-run Chinook Salmon: spawning and incubation
				Late all–run Chinook Salmon: spawning and incubation
				Steelhead: spawning and incubation
				Splittail: spawning and incubation
	River Flow—Feather River	CALSIM, Water years 1922–1994	Flow-habitat relationship	Spring-run Chinook Salmon: spawning and incubation
				Fall-run Chinook Salmon: spawning and incubation
				Steelhead: spawning and incubation
	River Flow—American River	CALSIM, Water years 1922–1994	Flow-habitat relationship	Fall-run Chinook Salmon: spawning and incubation
				Steelhead: spawning and incubation
	River Flow—San Joaquin	CALSIM, Water years 1922–1994	Qualitative assessment of flow effect	Fall-run Chinook Salmon: spawning and incubation
				Steelhead: spawning and incubation
	Delta Outflow (and X2)	CALSIM, Water years 1922–1994	Qualitative assessment of change in freshwater area in the Delta	Delta Smelt: spawning
				Striped Bass: spawning
	Reservoir Storage—Clair Engle, Shasta, Oroville, and Folsom	CALSIM, Water years 1922–1994	Qualitative assessment of changes in reservoir storage effects	Reservoir species: spawning and incubation

Table F-3. Continued

Assessed Environmental Correlate	Simulated Environmental Condition	Models Used to Simulate Environmental Conditions	Analytical Tool	Species: Life Stage
Rearing Habitat Quantity	River Flow—Trinity River	CALSIM, Water years 1922–1994	Qualitative assessment of flow effects	Coho Salmon: juvenile
	River Flow—Sacramento River at Keswick Dam, Colusa, and Verona	CALSIM, Water years 1922–1994	Low flow assessment based on flow-habitat relationship for salmon and steelhead; high flow assessment based on floodplain inundation for salmon and splittail	Winter-run Chinook Salmon: juvenile Spring-run Chinook Salmon: juvenile Fall-run Chinook Salmon: juvenile Late Fall–run Chinook Salmon: juvenile Steelhead: juvenile Splittail: juvenile
	River Flow—Feather River	CALSIM, Water years 1922–1994	Low flow assessment based on flow-habitat relationship	Spring-run Chinook Salmon: juvenile Fall-run Chinook Salmon: juvenile Steelhead: juvenile
	River Flow—American River	CALSIM, Water years 1922–1994	Low flow assessment based on flow-habitat relationship	Fall-run Chinook Salmon: juvenile Steelhead: juvenile
	River Flow—San Joaquin	CALSIM, Water years 1922–1994	Qualitative assessment of flow effects	Fall-run Chinook Salmon: juvenile Steelhead: juvenile
	Delta Outflow (and X2)	CALSIM, Water years 1922–1994	Change in rearing habitat area based on location of X2	Delta Smelt: juvenile and adult Striped Bass: juvenile
	Reservoir Storage—Clair Engle, Shasta, Oroville, and Folsom	CALSIM, Water years 1922–1994	Qualitative assessment of reservoir storage effects	Reservoir species: juvenile

Assessed Environmental Correlate	Simulated Environmental Condition	Models Used to Simulate Environmental Conditions	Analytical Tool	Species: Life Stage
Migration Habitat Conditions	River Flow—Sacramento River	CALSIM, Water years 1922–1994	Assessment of floodplain inundation for splittail; assessment of low flow effects for striped bass	Splittail: adult Striped Bass: egg and larvae
	Delta Channel Flows—Sacramento River, Delta Cross Channel, and Georgiana Slough	CALSIM, Water years 1922–1994	Pathway-survival relationship for chinook salmon and steelhead	Winter-run Chinook Salmon: juvenile Spring-run Chinook Salmon: juvenile Fall-run Chinook Salmon: juvenile Late Fall–run Chinook Salmon: juvenile Steelhead: juvenile
	Delta Channel Flows—San Joaquin River and head of Old River	CALSIM, Water years 1922–1994	Pathway-survival relationship for chinook salmon and steelhead	Fall-run Chinook Salmon: juvenile Steelhead: juvenile
	Delta Channel Flows—South Delta	DWRDSM2	Qualitative assessment based on barrier elevation and tidal flow volume	Fall-run chinook salmon: juvenile Delta Smelt: adult and larvae
	Dissolved Oxygen—San Joaquin River at Stockton	CALSIM, Water years 1922–1994; DWRDSM2	Qualitative assessment based on flow at Stockton	Fall-run Chinook Salmon: adult Steelhead: adult

Assessed Environmental Correlate	Simulated Environmental Condition	Models Used to Simulate Environmental Conditions	Analytical Tool	Species: Life Stage
Water Temperature	Water Temperature—Trinity River	CALSIM, Water years 1922–1994; U.S. Bureau of Reclamation Monthly Water Temperature Model	Temperature-survival relationship	Coho Salmon: adult, incubation, juvenile, smolt
	Water Temperature—Sacramento River at Keswick Dam, Bend Bridge, and Red Bluff Diversion Dam	CALSIM, Water years 1922–1994; U.S. Bureau of Reclamation Monthly Water Temperature Model	Temperature-survival relationship	Winter-run Chinook Salmon: adult, incubation, juvenile, smolt Spring-run Chinook Salmon: adult, incubation, juvenile, smolt Fall-run Chinook Salmon: adult, incubation, juvenile, smolt Late Fall–run Chinook Salmon: adult, incubation, juvenile, smolt Steelhead: adult, incubation, juvenile, smolt
	Water Temperature—Feather River	CALSIM, Water years 1922–1994; U.S. Bureau of Reclamation Monthly Water Temperature Model	Temperature-survival relationship	Spring-run Chinook Salmon: adult, incubation, juvenile, smolt Fall-run Chinook Salmon: adult, incubation, juvenile, smolt Steelhead: adult, incubation, juvenile, smolt
	Water Temperature—American River	CALSIM, Water years 1922–1994; U.S. Bureau of Reclamation Monthly Water Temperature Model	Temperature-survival relationship	Fall-run Chinook Salmon: adult, incubation, juvenile, smolt Steelhead: adult, incubation, juvenile, smolt
	River Flow—San Joaquin	CALSIM, Water years 1922–1994	Qualitative assessment of potential water temperature effects	Fall-run Chinook Salmon: adult, incubation, juvenile, smolt Steelhead: adult, incubation, juvenile, smolt

Assessed Environmental Correlate	Simulated Environmental Condition	Models Used to Simulate Environmental Conditions	Analytical Tool	Species: Life Stage
Food	River Flow—Trinity River	CALSIM, Water years 1922–1994	Qualitative assessment of flow effect	Coho Salmon: rearing
	River Flow—Sacramento River at Keswick Dam, Colusa, and Verona	CALSIM, Water years 1922–1994	Qualitative assessment of flow effect; high flow assessment of floodplain inundation	Winter-run Chinook Salmon: rearing Spring-run Chinook Salmon: rearing Fall-run Chinook Salmon: rearing Late Fall–run Chinook Salmon: rearing Steelhead: in-river rearing Splittail: rearing
	River Flow—Feather River	CALSIM, Water years 1922–1994	Qualitative assessment of flow effect	Spring-run Chinook Salmon: rearing Fall-run Chinook Salmon: rearing Steelhead: rearing
	River Flow—American River	CALSIM, Water years 1922–1994	Qualitative assessment of flow effect	Fall-run Chinook Salmon: rearing Steelhead: rearing
	River Flow—San Joaquin	CALSIM, Water years 1922–1994	Qualitative assessment of flow effect	Fall-run Chinook Salmon: rearing Steelhead: rearing
	Delta Outflow (and X2)	CALSIM, Water years 1922–1994	Qualitative assessment of change X2 location	Delta Smelt: rearing Striped Bass: rearing

Assessed Environmental Correlate	Simulated Environmental Condition	Models Used to Simulate Environmental Conditions	Analytical Tool	Species: Life Stage
Entrainment in Delta diversions	SWP and CVP Exports; particle transport	CALSIM, Water years 1922–1994; DWRDSM2; Particle Tracking Model (DSM2-PTM)	Export volume-entrainment loss relationships; particle transport-entrainment loss relationships for passive and active fish behavior	Winter-run Chinook Salmon: juvenile Spring-run Chinook Salmon: juvenile Fall-run Chinook Salmon (from Sacramento, Mokelumne, and San Joaquin Rivers): juvenile Late Fall–run Chinook Salmon: juvenile Steelhead: juvenile Delta Smelt: adult, larvae, juvenile Splittail: juvenile Striped Bass: egg, larvae, juvenile

Table F-4. Hypotheses Relating Change in an Environmental Correlate to a Species Response for All Evaluated Species

Environmental Correlate	Species	Hypothesis
Spawning Habitat Area	Chinook salmon	Spawning habitat area is a function of flow and reduced spawning habitat area will result in reduced egg survival
	Steelhead	Spawning habitat area is a function of flow and reduced spawning habitat area will result in reduced egg survival
	Delta smelt	Reduced spawning habitat area in response to flow (i.e., salinity intrusion) and physical disturbance will result in reduced egg survival
	Splittail	Spawning habitat area is a function of floodplain and bypass inundation and reduced spawning habitat area will result in reduced egg survival
	Striped Bass	Reduced spawning habitat area in response to flow (i.e., salinity intrusion) and physical disturbance will result in reduced egg survival
Rearing Habitat Area	Chinook salmon	Rearing habitat area within the stream channel is a function of flow and reduced rearing habitat area will result in reduced juvenile survival
		Rearing habitat area is a function of floodplain and bypass inundation and reduced rearing habitat area will result in reduced juvenile survival
	Steelhead	Rearing habitat area within the stream channel is a function of flow and reduced rearing habitat area will result in reduced juvenile survival
	Delta smelt	Reduced rearing habitat area in response to flow (i.e., estuarine salinity distribution) will result in reduced juvenile survival
	Splittail	Rearing habitat area is a function of floodplain and bypass inundation and reduced rearing habitat area will result in reduced juvenile survival
	Striped bass	Reduced rearing habitat area in response to flow (i.e., estuarine salinity distribution) will result in reduced juvenile survival
Migration Habitat Conditions	Chinook salmon	Low dissolved oxygen conditions in the San Joaquin River channel near Stockton can delay adult migration and reduce adult survival and fecundity
		Juvenile Chinook salmon survival is lower for fish migrating into the Delta Cross Channel (DCC) and Georgiana Slough
		Juvenile Chinook salmon survival is lower for fish migrating into Old River near Mossdale
	Steelhead	Same as Chinook salmon

Environmental Correlate	Species	Hypothesis
	Delta smelt	A clear relationship has not been supported by the available data
	Splittail	Migration habitat conditions are a function of floodplain and bypass inundation; and adult fecundity and survival of larvae and juveniles declines with reduced duration of inundation
	Striped bass	Egg survival is lower when Sacramento River inflow to the Delta is low
Water Temperature	Chinook salmon	Survival declines with increasing water temperature
	Steelhead	Survival declines with increasing water temperature
	Delta smelt	Not considered
	Splittail	Not considered
	Striped bass	Not considered
Food	Chinook salmon	Food production is a function of wetted channel area and inundated floodplain area and reduced food availability reduces survival
	Steelhead	Food production is a function of wetted channel area and reduced food availability reduces survival
	Delta smelt	An upstream shift in X2 results in lower food production and reduced food availability reduces survival
	Splittail	Food production is a function of inundated floodplain area and reduced food availability reduces survival
	Striped bass	An upstream shift in X2 results in lower food production and reduced food availability reduces survival
Entrainment	Chinook salmon	Entrainment-related mortality occurs in response to SWP and CVP pumping and the density of fish in the water diverted
	Steelhead	Entrainment-related mortality occurs in response to SWP and CVP pumping and the density of fish in the water diverted
	Delta smelt	Entrainment-related mortality occurs in response to SWP and CVP pumping and the density of fish in the water diverted
	Splittail	Entrainment-related mortality occurs in response to SWP and CVP pumping and the density of fish in the water diverted
	Striped bass	Entrainment-related mortality occurs in response to SWP and CVP pumping and the density of fish in the water diverted

Assessment of Change in Spawning Habitat Quantity

Chinook Salmon

The assessment of changes in river flow on Chinook salmon spawning habitat is based on the hypotheses that reduction in spawning habitat will result in reduced fry production. Change in spawning habitat area is assumed to result in a medium level of response—the difference between the proportional spawning habitat area (relative to the maximum available habitat area) for two simulated flow scenarios equals the expected change in survival.

Simulated river flows for 1922–1994 hydrologies are used in the assessment of effects on spawning habitat area. Relative to the base case, a meaningful change in habitat is assumed to occur when the change in river flow equals or exceeds approximately 10%. Average monthly flow is simulated by CALSIM and is used in the assessment of habitat effects. For existing measured flow conditions, daily flows vary by more than 10% from the average monthly flow in the Sacramento, Feather, and American Rivers. Daily variability around the monthly average exceeds 10% even during controlled flow periods (i.e., June–October). During storm events and spring runoff, daily variability around the monthly average has been substantially greater than 10%. The 10% criterion accounts for probable inaccuracies of habitat estimates based on average monthly flow. A change in average flow of less than 10% for a given month would likely not result in a measurable change in spawning habitat area.

Assessment of flow effects is based on the estimated spawning habitat area provided by flows during the spawning and incubation period. Relationships between streamflow and spawning habitat area have been developed from existing instream flow studies (Jones & Stokes 1994). Spawning habitat peaks at about 1,500 to 2,000 cfs on the American River. Change in spawning habitat area in response to flow changes is greatest when flow is less than about 1,000 cfs. For flows higher than 1,000 cfs, changes in flow have little effect on habitat area. Habitat area peaks at about 5,500 cfs in the Sacramento River and at about 500 to 2,500 cfs in the Feather River. Reduced flows that are less than the peak flow and increased flows that are higher than the peak flow both reduce spawning habitat area. For the purpose of this assessment, variation in flows that are greater than the peak flow (i.e., the flow that provides the maximum habitat area) is assumed to have minimal effect and is not included in the assessment of effects on spawning habitat.

Spawning habitat area is the minimum area that is provided by flow during the month of spawning and during subsequent months of incubation. Chinook salmon fry are assumed to emerge from the redd after 3 months of incubation. Therefore, flows during three consecutive months are considered in the calculation of spawning habitat area for Chinook salmon. The assumed occurrence of spawning each month is based on the timing shown in Table F-1.

The certainty of the assessment is low to medium. Evidence from existing research supports the relationship for cause and effect, but the magnitude of species response cannot reliably be predicted from a given magnitude change in spawning habitat area. Fish may use only small sections of the total area that appears suitable relative to gravel quality and flow depth and velocity. Superimposition of redds may be unpredictable. The proportion of spawning habitat used is not available; therefore, the assessment of effects on spawning habitat area assumes that all available spawning habitat is potentially used. The potential for redd superimposition is not considered.

High quality spawning habitat, including high quality spawning riffles and gravel, are more important than the "total area" used in this analysis. Flows can be used as a baseline to predict spawning and post-spawning success, but additional habitat measurements such as depth, velocity, spawning gravel quality, and water temperature are necessary for successful spawning and incubation. Burner (1951 in Healey 1991; Bjornn and Reiser 1991) observed Chinook salmon spawning in water as shallow as 0.16 foot (5 cm), Vronski (1972 in Healey 1991) found Chinook salmon spawning in water depths of 23.6 feet (720 cm). Thompson (1972 in Bjornn and Reiser 1991), who also studied water depth requirements for spawning, found Chinook salmon spawning in depths less than 0.8 foot (24 cm).

Flow velocity also affects spawning gravel selection; however, the range in water depth and velocity is very broad (Healey 1991). Literature values for water velocity range from 0.98 to 6.2 fps (30 to 189 centimeters per second [cm/s]). Studies in northern California found that Chinook salmon from the Yuba and Sacramento Rivers preferred velocities ranging from 1.55 to 2.95 fps and 0.9 to 2.7 fps, respectively (California Department of Fish and Game 1991a).

Generally, Chinook salmon require substrate that ranges in size from approximately 0.3 cm to 15 cm while steelhead prefer substrate no larger than 10 cm (Bjornn and Reiser 1991). Spawning habitat quality is correlated with gravel size and intra-gravel flow. Low intra-gravel flow may provide insufficient DO, contribute to growth of fungus and bacteria, and result in high levels of metabolic waste. High percentage of fines in gravel substrates can substantially limit intra-gravel flow, affecting the amount of spawning gravel available in the river (Healey 1991). Raleigh et al. (1986) concluded that optimal gravel conditions would include less than 5 to 10% fine sediments measuring 0.3 cm or less in diameter. In addition, alevins of Chinook salmon, steelhead, and coho salmon have been observed to have difficulty emerging in laboratory studies when gravels exceeded 30 to 40% fine sediments (Phillips et al. 1975 in Bjornn and Reiser 1991; Waters 1995).

The assessment assumes saturation of the spawning habitat. Spawning habitat needs for different species and runs using the same stream may vary substantially. Needs also vary from year to year and, depending on the abundance of spawning adults, may vary by orders of magnitude. For example, the current abundance of winter-run Chinook salmon is substantially less than the abundance of fall-run Chinook salmon; therefore, the spawning habitat need for winter-run Chinook salmon is substantially less than it is for fall-run. However, fewer spawning reaches support winter-run spawning. Therefore, the relationship may reflect possible effects. More detailed evaluation of the magnitude of effects and other aspects of the relationships is warranted.

Steelhead

The assessment of changes in river flow on steelhead spawning habitat is based on the hypotheses that reduction in spawning habitat will result in reduced fry production. Change in spawning habitat area is assumed to result in a medium level of response—a change in spawning habitat area results in a proportional change in fry abundance. The assessment of river flow effects on steelhead spawning habitat area is the same as applied to Chinook salmon. Spawning habitat area is the minimum area that is provided by flow during the month of spawning and during subsequent months of incubation. Steelhead fry are assumed to emerge from the redd after 2 months of incubation. Therefore, flows during two consecutive months are considered in the calculation of spawning habitat area for steelhead. The assumed occurrence of spawning each month is based on the timing shown in Table F-1.

The certainty of the assessment relationship is low, primarily because specific data on steelhead spawning in the Sacramento, Feather, and American Rivers are not extensive. Also, the magnitude of species response is weakly supported. It is possible that spawning habitat is not limiting and that the assessment overstates the habitat need. Adequate flows for spawning and incubation have been defined in previous years within different rivers. Flows can be used as a baseline to predict spawning and post-spawning success, but additional habitat measurements such as depth, velocity, spawning gravel quality, and water temperature are necessary for successful spawning and incubation. Flow-habitat relationships for steelhead are also substantially different from the relationships for Chinook salmon because substrate, depth, and velocity preferences differ. As with Chinook salmon, the relationships assume saturation of the spawning habitat. More detailed evaluation of the magnitude of effects and other aspects of the relationships is warranted.

Delta Smelt

The assessment of changes Delta inflow on delta smelt spawning habitat is based on the hypotheses that reduction in spawning habitat will result in reduced larval production. Implementation of the Intertie is unlikely to substantially affect environmental conditions (i.e., fresh water) that maintain the existing habitat area in the Delta. The extent of salinity intrusion into the Delta, as represented by the change in location of X2, will be evaluated to confirm minimal effect on spawning habitat area.

The certainty of the assessment relationship is minimal. Existing information does not indicate that spawning habitat is limiting. Very little is known about spawning habitat needs of delta smelt; therefore, the assumption that spawning habitat is not limiting is speculative. Spawning occurs in fresh water, based on collection of ripe females and larval catches. In drier years, most female and larval delta smelt have been found in the Sacramento River near Prospect Island and the Barker-Lindsey–Cache Slough complex (Wang and Brown 1993). In high outflow years, smelt are found in most of the Delta, Suisun Marsh, and the Napa River (Sweetnam 1999). In addition to poor understanding of spawning location, the primary spawning substrate in the Delta is unknown. Eggs are adhesive, and suitable substrate may be aquatic vegetation, rocks, or instream woody material (Moyle 2002).

Splittail

The assessment is based on the hypothesis that inundation of floodplain and bypasses during high flow years is needed to maintain population abundance. Change in spawning habitat area is assumed to result in a medium level of response—a change in spawning habitat area results in a proportional change in fry abundance.

Spawning habitat availability is dependent on inundation of floodplain and flood bypasses during January through April. The assessment is based on Sacramento River flow conditions that inundate the Sutter and Yolo Bypasses, the primary spawning areas for splittail. The Sutter Bypass is substantially inundated when Sacramento River flow near Colusa is greater than 25,000 cfs. The Yolo Bypass is substantially inundated when Sacramento River flow at Verona is greater than 65,000 cfs. Any reduction in the annual occurrence of flows that are greater than 25,000 cfs at Colusa and 65,000 cfs at Verona or reduction in duration of inundation periods lasting 4 to 8 weeks is considered to have an adverse effect. For simulated average monthly flow, inundation flows were assumed to be 14,000 cfs at Colusa and 40,000 at Verona. Lower flow volumes were used because the simulated monthly flows do not capture inundation that occurs in response to daily or weekly flow variation. Sacramento River flows that are reduced below 14,000 cfs at Colusa and 40,000 cfs at Verona are assumed to result in very large changes in habitat area and substantially affect spawning success. Loss of spawning conditions in any one year is assumed to adversely affect population abundance.

The certainty of the assessment relationship is medium to high based on the historical response of splittail populations to bypass flooding. A significant positive relationship exists between splittail year-class strength and Sacramento River outflow during the spawning season (Daniels and Moyle 1983; Meng and Moyle 1995; Sommer et al. 1997). Spawning generally has been reported to begin in late February or early March, with peaks in late March and April (Baxter et al. 1996) in flooded shallow areas with flowing water (Moyle et al. 2000). Adult splittail forage and spawn among a variety of vegetation types that include trees, brush, and herbaceous vegetation. Splittail use a number of habitats for spawning, including vegetated tidal slough and Delta channel edges, inundated floodplain, and possibly vegetated edges of riverine pools and backwaters. Inundated floodplain appears to provide the best conditions for successful spawning. Splittail are believed to spawn in open areas less than 1.5 meters deep, covered with dense annual vegetation, where water temperature does not exceed about 16ºC (Moyle et al. 2000), and salinity ranges from 0 to 10 ppt. Adults remain in the flooded areas until spawning is completed or water depth and temperatures trigger movement. The highest population levels are seen during wet years and when floodplain is inundated for an extended period of time. Evidence from both the Yolo Bypass and the Cosumnes floodplain suggests that strong year classes of splittail develop mainly in years when floodplains are inundated continuously during March and April (Sommer et al. 1997; Moyle et al. 2000). Two major conclusions are that the population is dominated by year classes produced in wet years and that the timing and duration of floodplain inundation in these years are key factors in determining the strength of these year classes. Variation in year-class strength appears to be controlled primarily by the extent to which floodplain habitat is available for spawning and early rearing. A positive relationship between days of bypass inundation and abundance of age-0 splittail indicates that the largest year classes are produced when floodplain habitat is available for a month or more. The positive relationship with inundation is likely related to the period needed for successful adult immigration and spawning, egg incubation, and emigration of larvae (Sommer et al. 1997).

In dry years, young splittail have been captured in the Sacramento River (Baxter 2003), indicating that spawning may occur along the river margin. Splittail may also spawn in the Yolo Bypass in dry years, using areas inundated by flow from Cache and Putah Creeks and flow from the Colusa Basin Drain (Sommer et al. 2002). The response to inundation is highest in wet years.

Striped Bass

Spawning habitat in the Delta may be limiting during drier years (California Department of Fish and Game 1992). Delta outflow maintains the spawning habitat area within the Delta. The extent of salinity intrusion into the Delta (i.e., change in location of X2) will be evaluated to determine the potential effect on spawning habitat area.

The certainty of the assessment relationship is low, primarily because the magnitude of the species response (i.e., spawning success) to reduced freshwater area in the lower Delta is unknown. Spawning is dependent on three factors: temperature, flow, and salinity (Clark and Pearson 1978). During high-flow years, spawning takes place in the Sacramento River starting above Colusa and extends to below the mouth of the Feather River. In low-flow years, spawning occurs in the Sacramento River from Isleton to Butte City. Spawning in the San Joaquin River channel in the Delta extends from Venice Island to Antioch (Moyle 2002).

Rearing Habitat Quantity

Chinook Salmon

The assessment of changes in river flow on Chinook salmon rearing habitat is based on the hypotheses that reduction in rearing habitat will result in reduced juvenile production. Change in rearing habitat area is assumed to result in a medium level of response—a change in rearing habitat area results in a proportional change in juvenile abundance.

Rearing habitat area tends to reach maximum abundance at very low flows that inundate most of the river channel area and at very high flows that inundate floodplain. Under low-flow (i.e., in-bank) conditions, rearing habitat area declines in response to increased average velocity as flow increases. The reduction in habitat area with increasing flow results from the preference of low velocity areas by juvenile Chinook salmon fry. The relationship may be misleading because the flow-habitat relationship may not adequately reflect local habitat conditions (i.e., availability of low velocity) or the importance of flow-related habitat quality elements (e.g., water temperature conditions or cover and prey availability). The analysis of potential effects on rearing habitat area relies on the assessment of changes to low-flow conditions (e.g., flows less than the 25^{th} percentile during critical and dry year types). Although an actual 10% change in flow may have measurable effects depending on river form, change in simulated monthly average flow of low magnitude (i.e., a flow that is less than the 25^{th} percentile) that exceeds 10% is assumed to affect rearing habitat area. Average monthly flow is simulated by CALSIMII and is used in the assessment of habitat effects. For existing measured flow conditions, daily flows vary by more than 10% from the average monthly flow in the Sacramento, Feather, and American Rivers. Daily variability around the monthly average exceeds 10% even during controlled-flow periods (i.e., June–October). During storm events and spring runoff, daily variability around the monthly average has been substantially greater than 10%. The 10% criterion accounts for probable inaccuracies of habitat estimates based on average monthly flow. A change in average monthly flow of less than 10% would likely not result in a measurable change in rearing habitat area.

Increased low-magnitude flow is assumed to be beneficial, and reduced low-magnitude flow is assumed to be detrimental. The proportional change in flow is assumed to result in the same proportional change in juvenile abundance. The proportion of the rearing period affected and the timing change relative to the rearing period are considered in the assessment of the annual effect. The assumed occurrence of rearing each month is based on Table F-1.

The rearing habitat relationship for floodplain is assumed to be similar to the relationship described for splittail spawning. Rearing habitat availability is dependent on inundation of floodplain and flood bypasses during November through April. The Sutter and Yolo Bypasses are primary rearing areas and are dependent on relatively high flows for inundation. Any reduction in simulated monthly average flows that exceed 14,000 cfs at Colusa and 40,000 cfs at Verona is considered to have an adverse effect. Although change in rearing habitat area would likely result in a low level of response, Sacramento River flows that are reduced below 14,000 cfs at Colusa and 40,000 cfs at Verona are assumed to result in relatively large changes in habitat area and may substantially affect rearing success.

The certainty of the assessment relationship for in-channel habitat is low because the relationship of flow to rearing habitat area and the species response to flow-related changes in rearing habitat area are unknown. The certainty of the assessment relationship for inundated floodplain habitat is low to medium, reflecting the documented potential benefits to rearing juvenile Chinook salmon. Recent studies have shown that juvenile salmon have increased growth on floodplains. Use of floodplain habitat by juvenile Chinook salmon has been well documented (Jones & Stokes 1993, 1999; California Department of Water Resources 1999; Sommer et al. 2001). Sommer et al. 2001 found that floodplain habitat provides better rearing and migration habitat for juvenile Chinook salmon than the main river channel. The apparent growth rate of Chinook salmon in the Yolo Bypass ranged from 0.55 to 0.80 millimeters (mm) per day, while growth rates in the main channel of the Sacramento River ranged from 0.43 to 0.52 mm per day. The faster growth rate in the Yolo Bypass may be attributed to increased prey consumption associated with greater availability of drift invertebrates and warmer water temperature.

In addition to floodplain availability, other environmental conditions such as flow, depth, velocity, and water temperature affect the growth and survivability of juveniles. In rivers, increases in flow provide edge habitat where terrestrial vegetation on the channel edge increases the diversity of habitat conditions. These areas are more productive and increase growth in juvenile fish. Deeper inundation provides more overhead cover and protection from avian and terrestrial predators than shallow water (Everest and Chapman 1972 in Jackson 1992). In broad, low-gradient rivers, change in flow can greatly increase or decrease the lateral area available to juvenile Chinook salmon, particularly in riffles and shallow glides (Jackson 1992).

The quality of the habitat is more critical to survival than the gross area. Caution should be exercised with the assessment because the effect of the flow on habitat is very site-specific within different reaches of the same river. While flows are important for providing additional habitat, other environmental factors such as depth, velocity, and water temperature affect rearing and growth. Although juvenile Chinook salmon do not appear to prefer a particular depth (Jackson 1992), Brett (1952 in Jackson 1992) reported water depths from 1 to 4 feet as optimal for rearing. Raleigh et al. (1986) reported preferred water depth ranging from 0.5 to 3.0 feet. Water velocity is a particularly important factor in determining where juvenile salmonids occur because it determines the energy requirements for maintaining position and the amount of food delivered to a particular location. Juvenile salmonids tend to select positions that maximize energy gain, but these positions can be altered by interaction with other fish and the presence of cover (Shirvell 1990). Water velocity preferred by Chinook salmon varies with size. Larger fish occupy higher velocity and deeper areas than small fish, potentially gaining access to abundant food and avoiding predatory birds (Bjornn and Reiser 1991; Jackson 1992). The mean water column velocity preferred by juvenile Chinook salmon is between 0.3 and 1.5 fps.

Steelhead

The assessment of changes in river flow on steelhead rearing habitat is based on the hypotheses that reduction in rearing habitat will result in reduced juvenile production. Change in rearing habitat area is assumed to result in a medium level of response—a change in rearing habitat area results in a proportional change in juvenile abundance. The assessment of changes in river flow on steelhead rearing habitat is the same as described for Chinook salmon for low-flow conditions. Steelhead have not been observed to use inundated floodplain extensively; therefore, the analysis of floodplain inundation applied to Chinook salmon is not applied to steelhead.

The certainty of the assessment relationship is minimal because of limited information on rearing habitat, growth, and survival. Environmental conditions such as depth, velocity, cover, and water temperature affect the growth and survivability of juveniles. Small juvenile steelhead prefer relatively shallow areas. These include pool tailouts characterized by cobble and boulder bottoms or riffles less than 24 inches deep (Flosi et al. 1998). Larger juveniles live in higher-velocity water, although they may prefer areas with low bottom velocity (Everest and Chapman 1972). There has been conflicting evidence that shows juvenile steelhead use of instream woody material. Several studies found that juveniles were rarely associated with woody cover. Shirvell (1990) and found that instream woody material was an important habitat component. Generally, cover provides protection from predators, rest from high currents, and sources of food.

Change in river flow may decrease the quantity of rearing habitat but may not decrease the quality. Using the same flow model used for Chinook salmon will detect changes in flow, but not the change in habitat quality. Because steelhead rearing habitat is not as well-defined as for Chinook salmon, comparisons may not be appropriate. More detailed evaluation of the magnitude of effects and other aspects of the relationships is warranted.

Delta Smelt

The assessment is based on the hypothesis that rearing habitat area is a function of Delta outflow and that juvenile production is affected by changes in rearing habitat area. Delta outflow may affect estuarine rearing habitat for delta smelt and other estuarine species (Moyle et al. 1992). The location of X2 (i.e., the approximate location of the 2 ppt isohaline relative to the Golden Gate Bridge) can be used to estimate the estuarine habitat area within the preferred salinity range for a species (Unger 1994). The estimated salinity preference for delta smelt during estuarine rearing is assumed to range from 0.3 ppt to 1.8 ppt. The range represents the 10^{th} and 90^{th} percentiles of the salinity over which delta smelt are distributed.

The geographic location of the upstream and downstream limits of estuarine rearing habitat for delta smelt is computed from X2 that was calculated from average monthly Delta outflow as simulated by the CALSIMII model. Monosmith (1993) showed that when X2 is known, the average position of other salinity gradients can be estimated. The position of the 0.3 ppt isohaline equals 0.35 x X2, and the position of the 1.8 ppt isohaline equals 0.74 x X2. The constants were computed with a nonlinear regression model (Unger 1994).

The estuarine rearing habitat area is the surface area between the location of the upper and lower preferred salinity isohalines (Unger 1994). Surface area was used as an index of habitat because habitat surface area is positively correlated with habitat volume. The shore-to-shore surface area was estimated for each kilometer segment of the estuary from the Golden Gate Bridge to the Delta. Total surface area between the upper and lower salinity preference is the sum of all segments between the estimated locations of the isohalines.

For the No Action Alternative and the Proposed Action, the habitat areas computed for each month were divided by the maximum habitat area for the No Action Alternative, 1922–1994 simulation. The resulting proportional habitat area for a month under the No Action Alternative was subtracted from the proportional habitat area for the Proposed Action for the same month. The difference is the percent change in estuarine rearing habitat area. The percent change in estuarine rearing habitat area is assumed to represent the expected change in survival.

The certainty of the assessment relationship is low, primarily because the magnitude of species response is weakly supported. Rearing habitat is important in Suisun Bay, and when low salinity water is covering shoal areas, these areas are more productive and favorable than deep channel areas (Moyle et al. 1992). Delta smelt are more abundant in northern Suisun Bay than in the deeper ship channel to the south. While these studies indicate that shoal areas are better rearing grounds for smelt, more detailed evaluation of the magnitude of effects and other aspects of the relationships is warranted.

Splittail

The assessment is based on the hypothesis that rearing habitat area is a function of inundated floodplain and that juvenile production is dependent on rearing habitat area. The assessment is the same as described for adult splittail under spawning habitat quantity.

The certainty of the assessment relationship is medium to high. Variation in year-class strength appears to be controlled primarily by the extent to which floodplain habitat is available for spawning and early rearing. A positive relationship between days of bypass inundation and abundance of age-0 splittail indicates that the largest year classes are produced when floodplain habitat is available for a month or more (Sommer et al. 1997). Seasonally flooded habitat provides abundant food and minimizes predation losses because of the temporary availability of the habitat, relatively shallow depths, turbid waters, and dense cover provided by flooded vegetation. Juvenile and larvae splittail survival and growth improve with abundant and high quality food sources in the floodplain (Moyle et al. 2000). Floodplains are more productive than the main channel of rivers because these broad and shallow vegetated areas are richer in nutrients than deeper and narrower river channels (Sommer et al. 2001).

Striped Bass

The assessment is based on the hypothesis that rearing habitat area is a function of Delta outflow and that juvenile production is affected by changes in rearing habitat area. The assessment is the same as described for delta smelt except that the estimated salinity preference for striped bass during estuarine rearing is assumed to range from 0.1 ppt to 2.5 ppt. The range represents the 10^{th} and 90^{th} percentiles of the salinity over which larval and early juvenile striped bass are distributed. The position of the 0.1 ppt isohaline equals 0.11 x X2 and the position of the 2.5 ppt isohaline equals 0.82 x X2. The constants were computed with a nonlinear regression model (Unger 1994).

The certainty of the assessment is low to medium because of conflicting data on survival of larval striped bass and the importance of estuarine rearing habitat. High flows seem to be key in determining survival of young bass, and higher survival is seen at higher outflow (California Department of Fish and Game 1992). The embryos and larvae of striped bass are planktonic, and high flows may facilitate movement to appropriate rearing habitat. Growth and survival of larval fish are highest in brackish water because of reduced energy costs for osmoregulation (Moyle 2002). Existing data are confounded by potential relationships among rearing habitat area, transport flows, SWP and CVP pumping, and other interrelated factors.

Migration Habitat Conditions

Chinook Salmon

Flows that occur in Central Valley rivers generally support migration of adult and juvenile Chinook salmon. Migration habitat conditions that are related to river flows are not assessed.

The assessment of adult migration in the lower San Joaquin River considers project effects on DO. The hypothesis is that low DO conditions in the San Joaquin River channel near Stockton block migration of fall-run Chinook salmon returning to the San Joaquin River basin. The expected effects of the project on flow and subsequent effects on DO levels are used to determine potential blockage of adult Chinook salmon. DO levels less than 5 milligrams per liter (mg/l) are assumed to block upstream migration of Chinook salmon in the San Joaquin River near Stockton. The effect of blockage on the population is relative to the proportion of the adult migration affected during October through November and the expected delay. San Joaquin River flows between 1,000 cfs and 10,000 cfs appear to provide possibilities for managing DO in the San Joaquin River near Stockton.

DO-level effects on adult Chinook salmon are well established, and delay decreases the spawning success through effects on fecundity and survival. At water temperatures greater than 50°F, Chinook salmon require levels of DO greater than 5 mg/l. Optimum DO is 12 mg/l (Raleigh et al. 1986). Hallock (1970) observed that Chinook salmon avoided water temperatures greater than 66°F if DO was less than 5 mg/l. The certainty of the assessment relationship is low because water temperature and DO levels are interrelated and it is not clear that DO levels alone have blocked migration of adult Chinook salmon in the San Joaquin River near Stockton.

The assessment of juvenile Chinook salmon migration through the Delta focuses on Delta channel pathways and effects on survival of juvenile Chinook salmon. The hypothesis is that alternative migration pathways have different effects on juvenile Chinook salmon survival from the Sacramento and San Joaquin Rivers. Juvenile Chinook salmon are assumed to move in proportion to flow; therefore, an increase in the proportion of flow diverted off the Sacramento River through the DCC and Georgiana Slough would be expected to increase movement of juvenile Chinook salmon into the DCC and Georgiana Slough. The proportion of Sacramento River flow diverted into the DCC and Georgiana Slough is calculated from the simulated flow for the Sacramento River at Freeport and for the DCC and Georgiana Slough. The simulated proportion of juvenile Chinook salmon that move into the DCC and Georgiana Slough is assumed equal to the simulated proportion of flow diverted into the DCC and Georgiana Slough. Survival is greater for fish that remain in the Sacramento River channel (Newman and Rice 1997; Brandes and McLain 2001).

The certainty of the assessment relationship is medium to high for juvenile Chinook salmon in the Sacramento River. Juvenile Chinook salmon survival is lower for fish migrating through the central Delta (i.e., diverted into the DCC and Georgiana Slough) than for fish continuing down the Sacramento River (Newman and Rice 1997).

An increase in the proportion of flow diverted off the San Joaquin River and into Old River would be expected to increase movement of juvenile Chinook salmon into Old River. The proportion of San Joaquin River flow diverted into Old River is based on the simulated flow for the San Joaquin River at Vernalis and for Old River. The simulated proportion of juvenile Chinook salmon that move into Old River is assumed equal to the simulated proportion of flow diverted into Old River. Survival appears to be greater for juvenile Chinook salmon that remain in the San Joaquin River, although the difference in survival for the pathways has not proved to be statistically different through all years (Brandes and McLain 2001; San Joaquin River Group Authority 2003).

In the San Joaquin River, juvenile Chinook salmon survival appears to be lower for fish migrating into Old River near Mossdale than for fish continuing down the San Joaquin River past Stockton (Brandes and McLain 2001). The certainty of the assessment relationship is low to medium for juvenile Chinook salmon in the San Joaquin River because the survival relationship is not clearly supported by data collected in all years (San Joaquin River Group Authority 2003).

Steelhead

Flows that occur in Central Valley rivers generally support migration of adult and juvenile steelhead. Migration habitat conditions that are related to river flows are not assessed.

The assessment for adult and juvenile steelhead migration through the Delta is similar to the assessment described for adult and juvenile Chinook salmon, taking into account differences in timing and distribution. The certainty of the assessment relationship is low because of lack of information about movement of migrating adult and juvenile steelhead in the Delta. Effects of DO levels and migration through the Delta have not been studied specifically for steelhead and may differ from the effects on Chinook salmon.

Delta Smelt

Existing information does not indicate clear relationships between migration habitat conditions and adult, larval, and juvenile survival. Effects of environmental conditions (e.g., net and tidal flow) on adult migration are unknown. The effect of net flow on larval and early juvenile movement and survival is unsupported by available data.

The assessment of larval and juvenile entrainment in CVP and SWP exports is assumed to reflect the potential effect of changes in Delta flow conditions on movement and survival of larvae and early juvenile delta smelt. An additional analysis of flow effects is not applied.

Splittail

Existing information indicates that high flow and the inundation of floodplain initiates upstream adult migration (Garman and Baxter 1999). The assessment of spawning habitat quantity for adult splittail (see Spawning Habitat Quantity) depicts the potential effects on adult, larval, and early juvenile movement onto and off of the floodplain.

Adult migration movements begin sometime between late November and early January and continue into March. Upstream movement is seen when high flow events occur during February–April (Garman and Baxter 1999), but other studies indicate that migration occurs when inundated floodplain habitat is available earlier in the water year. As water levels recede in the floodplain, juvenile splittail return to the main channel and ultimately to tidal areas in response to decreased depth and increasing water temperature (15ºC–18ºC) (Moyle et al. 2000).

Striped Bass

The assessment of larval and juvenile entrainment in CVP and SWP exports is assumed to reflect the potential effect of changes in Delta flow conditions on movement and survival of larvae and early juvenile striped bass. An additional analysis of Delta flow effects is not applied.

Implementation of the Intertie is not expected to substantially affect Sacramento River inflow during striped bass spawning. Sacramento River flow at Freeport will be evaluated to confirm minimal effect on flows less than 11,000 cfs during April and May. The certainty of the assessment relationship is medium because of fairly well established relationships between flow and movement of eggs and larvae. Available information indicates that low Sacramento River flow (i.e., less than 13,000 cfs at Freeport) may affect survival of striped bass between the egg and 6-mm larvae stage (California Department of Fish and Game 1992). The mechanisms that may reduce survival are: low velocity that results in eggs and larvae settling to the river bottom and ultimately dying; delay in reaching higher quality nursery areas; increased exposure to toxic substances; and more exposure to entrainment.

Water Temperature

Water temperature within the Sacramento–San Joaquin River basin is an issue primarily for coldwater species, including Chinook salmon and steelhead.

Chinook Salmon

The assessment is based on the hypothesis that survival of freshwater life stages (adult migration, spawning and incubation, rearing, and juvenile migration) is dependent on suitable water temperatures in Central Valley rivers. Monthly water temperature effects are estimated for selected locations and all life stages of Chinook salmon. Simulated monthly water temperature indicates the potential direction of effect when considered relative to species water temperature requirements. For the purposes of this impact assessment, survival indices are based on experimental tolerance studies reported in the literature, a use recommended by the U.S. Environmental Protection Agency (EPA) and Armour (cited in Sullivan et al. 2000; Armour 1991).

Water temperature for the Trinity, Sacramento, Feather, and American Rivers is simulated by the Bureau of Reclamation's temperature model. The model simulates monthly temperature conditions in CVP and SWP reservoirs and at locations downstream from the discharge points, providing estimates of monthly temperature. Model inputs include initial storage and temperature conditions, simulated reservoir storage, simulated model segment inflow, simulated model segment outflow, evaporation, solar radiation, and average air temperature. Release temperatures from reservoirs are computed for each outlet level of the dams. River temperatures are computed for each month at river locations represented by specific model segments. River temperatures are based on the quantity and temperature of the simulated reservoir release, normal climatic conditions, and tributary accretions. During warmer months (March through October), reservoir releases warm with distance downstream.

Temperature survival indices were estimated for Chinook salmon life stages, including adult migration, spawning and incubation, rearing, and smolt migration (Table F-5). The temperature survival indices are estimated from curves fitted to available survival data. The survival indices applied in this assessment support the comparison of alternatives and should not be considered specific management recommendations or targets for water temperature management in Central Valley rivers.

The certainty of the assessment relationship is high. Water temperature effects on fish are well established and can be used to predict survival. As water temperature increases toward the extremes of the tolerance range of a fish, biological responses, such as impaired growth and risk of disease and predation, are more likely to occur (Myrick and Cech 2001; Sullivan et al. 2000). Acceptable water temperatures identified in the available literature for Chinook salmon and steelhead life stages fall within a relatively broad range. Conclusive studies of the thermal requirements completed for Chinook salmon and steelhead in Central Valley streams are limited (Myrick and Cech 2001). Based on a literature review, conditions supporting adult Chinook salmon migration are assumed to deteriorate as temperature warms between 54ºF and 70ºF (Hallock 1970 as cited in McCullough 1999). For Chinook salmon eggs and larvae, survival during incubation is assumed to decline with increasing temperature between 54ºF and 61ºF (Myrick and Cech 2001; Seymour 1956 cited in Alderice and Velsen 1978). For juvenile Chinook salmon, survival is assumed to decline as temperature warms from 64ºF to 75ºF (Myrick and Cech 2001; Rich 1987). Relative to rearing, Chinook salmon require cooler temperatures to complete the parr-smolt transformation and to maximize their saltwater survival. Successful smolt transformation is assumed to deteriorate at temperatures ranging from 63ºF to 73ºF (Marine 1997 cited in Myrick and Cech 2001; Baker et al. 1995). Juveniles are more at risk in the Delta, and water temperatures over the optimal limit increase mortality. Baker et al. (1995) developed a statistical model to estimate the influence of temperature on the survival of Chinook salmon smolts migrating through the Delta. The model estimated that Chinook salmon released at Ryde and migrating to Chipps Island undergo 50% mortality at 71.6ºF to 75.2ºF (22ºC to 24ºC).

Table F-5. Temperature Survival Indices for Chinook Salmon and Steelhead

	Chinook Salmon				Steelhead			
Water Temperature (°F)	Adult Migration	Spawning/ Incubation	Juvenile Rearing	Smolt Migration	Adult Migration	Spawning/ Incubation	Juvenile Rearing	Smolt Migration[1]
50	100%	100%	100%	100%	100%	100%	100%	100%
51	100%	100%	100%	100%	100%	100%	100%	100%
52	100%	100%	100%	100%	100%	100%	100%	100%
53	100%	100%	100%	100%	100%	100%	100%	100%
54	100%	100%	100%	100%	100%	98%	100%	100%
55	100%	99%	100%	100%	100%	91%	100%	100%
56	100%	96%	100%	100%	99%	80%	100%	100%
57	100%	90%	100%	100%	98%	63%	100%	100%
58	99%	82%	100%	100%	96%	37%	100%	100%
59	97%	69%	100%	100%	94%	0%	100%	100%
60	94%	52%	100%	100%	90%	0%	100%	100%
61	91%	29%	100%	100%	87%	0%	100%	100%
62	87%	0%	100%	100%	82%	0%	100%	100%
63	81%	0%	100%	100%	76%	0%	100%	100%
64	74%	0%	100%	100%	69%	0%	100%	100%
65	66%	0%	100%	99%	61%	0%	100%	99%
66	57%	0%	97%	96%	52%	0%	100%	96%
67	46%	0%	93%	92%	42%	0%	98%	92%
68	33%	0%	87%	87%	29%	0%	95%	87%
69	18%	0%	77%	79%	16%	0%	90%	79%
70	0%	0%	65%	69%	0%	0%	83%	69%
71	0%	0%	48%	57%	0%	0%	73%	57%
72	0%	0%	27%	42%	0%	0%	61%	42%
73	0%	0%	0%	23%	0%	0%	45%	23%
74	0%	0%	0%	0%	0%	0%	25%	0%
75	0%	0%	0%	0%	0%	0%	0%	0%

[1] Survival indices for Chinook salmon smolt migration are assumed to apply to steelhead; indices for adult migration, juvenile rearing, and juvenile migration of Chinook salmon are assumed to apply to coho salmon in the Trinity River.

Note: The survival indices in this table support the comparison of alternatives and should not be considered specific management recommendations or targets for water temperature management in Central Valley rivers.

Steelhead

The assessment is based on the hypothesis that survival of freshwater life stages (i.e., adult migration, spawning and incubation, rearing, and juvenile migration) is dependent on suitable water temperatures in Central Valley rivers. The assessment is the same as described for Chinook salmon except that temperature survival indices were estimated for steelhead life stages (Table F-5).

The certainty of the assessment relationship is high. Water temperature effects on fish are well established and can be used to predict survival. For steelhead, successful adult migration and holding are assumed to deteriorate as water temperature warms between 52ºF and 70ºF. Adult steelhead appear to be much more sensitive to thermal extremes than are juveniles (National Marine Fisheries Service 1996a; McCullough 1999). Conditions supporting steelhead spawning and incubation are assumed to deteriorate as temperature warms between 52ºF and 59ºF (Myrick and Cech 2001). Juvenile rearing success is assumed to deteriorate at water temperatures ranging from 63ºF to 77ºF (Raleigh et al. 1984; Myrick and Cech 2001). Relative to rearing, smolt transformation requires cooler temperatures, and successful transformation occurs at temperatures ranging from 43ºF to 50ºF. Juvenile steelhead, however, have been captured at Chipps Island in June and July at water temperatures exceeding 68ºF (Nobriega and Cadrett 2001). Given the movement of steelhead at water temperatures warmer than required for successful smolt transformation, the water temperature criteria applied to migration of steelhead smolt are assumed to be the same as those applied to assess water temperature effects on Chinook salmon smolt migration.

Food

Chinook Salmon

The assessment for Chinook salmon under Rearing Habitat Quantity is assumed to reflect the potential effects on food for juvenile Chinook salmon. The assessment is based on the hypothesis that food production and availability are directly related to inundated channel and floodplain area. The certainty of the assessment relationship is low to medium, primarily because the relationship between river flow and food availability for juvenile Chinook salmon is relatively unknown. Use of floodplain habitat by juvenile Chinook salmon, however, has been well documented (Jones & Stokes 1993, 1999; California Department of Water Resources 1999; Sommer et al. 2001). Sommer et al. 2001 found that floodplain habitat provides better rearing and migration habitat for juvenile Chinook salmon than the main river channel. The apparent growth rate of Chinook salmon in the Yolo Bypass ranged from 0.55 to 0.80 mm per day, while growth rates in the main channel of the Sacramento River ranged from 0.43 to 0.52 mm per day. The faster growth rate in the Yolo Bypass may be attributable to increased prey consumption associated with greater availability of drift invertebrates and warmer water temperature.

Steelhead

The assessment of effects on food for steelhead is the same as described for Chinook salmon for in-channel habitat. Steelhead do not appear to use floodplain habitat as extensively as juvenile Chinook salmon; therefore, assessment of effects on floodplain food sources are not considered. The certainty of the assessment relationship is minimal, primarily because the relationship between river flow and food availability for juvenile steelhead is relatively unknown.

Delta Smelt

The assessment for delta smelt under Rearing Habitat Quantity is assumed to reflect the potential effects on food for juvenile and adult delta smelt in estuarine rearing habitat. The assessment is based on the hypothesis that food production is directly related to the location of X2 in Suisun Bay and that food availability affects smelt survival.

The certainty of the assessment relationship is low to medium, primarily because the magnitude of species response is weakly supported. Rearing habitat in Suisun Bay is assumed to be important to maintaining smelt population abundance. Under similar salinity conditions, shoal areas are more productive and favorable for delta smelt feeding than deep channel areas (Moyle et al. 1992). Delta smelt are more abundant in northern Suisun Bay than in the deeper ship channel to the south (Bennett 2003), and postlarvae are larger and have higher feeding success (Bennett 2003). While the studies indicate that shoal areas are better rearing grounds for smelt, more detailed evaluation of the magnitude of effects and other aspects of the relationships is warranted.

Splittail

The assessment for splittail under Spawning Habitat Quantity and Rearing Habitat Quantity is assumed to reflect the potential effects on food for larval, juvenile, and adult splittail. The assessment is based on the hypothesis that effects of food production and availability on splittail abundance is directly related to inundated floodplain area. The certainty of the assessment relationship is medium. Two studies on the Yolo Bypass (Sommer et al. 2001) and the Cosumnes River (Moyle unpublished data) indicate an increase of food resources on floodplain habitat. Also the longer the floodplain is available, the longer juvenile splittail can rear and the more food they can obtain (see Rearing Habitat Quantity).

Striped Bass

The assessment for striped bass under rearing habitat quantity is assumed to reflect the potential effects on food for juvenile bass in estuarine rearing habitat. The assessment is based on the hypothesis that food production is directly related to the location of X2 in Suisun Bay and that food availability affects striped bass survival. The assessment of effects on food for striped bass is the same as described for delta smelt. The certainty of the assessment relationship is medium, primarily because the magnitude of species response is weakly supported.

Entrainment

Entrainment of fish with water diverted from the Delta has been identified as a primary concern for Chinook salmon, delta smelt, and other fish species (U.S. Fish and Wildlife Service 1996). More than 1,800 agricultural, municipal, and industrial diversions have the potential to entrain fish with diverted water. The CVP and SWP pumping plants, the two largest diversions from the Delta, entrain thousands of fish annually. The environmental conditions that influence the number of fish lost to diversions include:

- abundance, distribution, and movement of fish in the Delta;
- diversion location, volume, duration, frequency, and timing (e.g., seasonal, diurnal, tidal phase);
- effects of net and tidal flows on the movement of fish;
- effects of diversions on net and tidal flows;
- direct and indirect (i.e., net and tidal flow) effects of barriers on fish movement;
- efficacy of fish salvage, handling, holding, and transport facilities and procedures; and
- predation vulnerability prior to entrainment and associated with salvage facilities and procedures.

The Intertie includes changes in water supply operations that potentially affect the number of fish entrained by SWP and CVP pumping and in other diversions. The timing and volume of SWP and CVP pumping is potentially altered with implementation of the Intertie.

Although entrainment is well documented at the SWP and CVP facilities, the relationships between affected environmental conditions, the number of fish entrained, and the potential population effect remain relatively weakly supported.

For this impact assessment, entrainment of Delta fishes is based primarily on the hypothesis that the number of fish entrained is directly related to export volume and an assumed density of fish in the water diverted. Salvage and entrainment loss are assumed to increase linearly with increased exports.

For Chinook salmon, historical loss estimates (i.e., loss per second per cubic foot) provide the basis for assessing effects of changes in SWP and CVP pumping. DFG has calculated the number of Chinook salmon in each run that are salvaged and lost at the SWP and CVP pumping facilities. The median loss per second per cubic foot for each month, each salmon run, and each facility for 1992–2002 was multiplied by the simulated SWP and CVP pumping volume (cfs) to arrive at total entrainment loss estimates. The total annual entrainment loss for each salmon run for each action alternative was first compared to the total annual entrainment loss for the No Action Alternative. To provide a context of impact level, entrainment loss was compared to estimated annual production. Historical juvenile production was estimated by the method applied by the National Marine Fisheries Service (NOAA Fisheries) for winter-run Chinook salmon (Winter Run Juvenile Production Estimate [JPE] Estimator Program). Juvenile production entering the Delta was estimated for fall-, late fall–, winter-, and spring-run Chinook salmon from the Sacramento and San Joaquin River systems.

For all other species (steelhead, delta smelt, splittail, and striped bass), historical salvage estimates (i.e., salvage per second per cubic foot) provide the basis for assessing effects of changes in SWP and CVP pumping on entrainment. Annual life-stage production estimates are not available. The analysis, therefore, is based on simulated change in salvage that provides an indication of the possible magnitude of change in entrainment loss. The impact on the population is assessed qualitatively based on a range of possible factors (e.g., fish size, fish distribution within and entering the Delta).

DFG has calculated the number of steelhead, delta smelt, splittail, and striped bass that are salvaged at the SWP and CVP pumping facilities. The monthly pattern of salvage numbers and fish size was used in the assessment. The median salvage per second per cubic foot for each month and each facility for 1980–2002 was multiplied by the simulated SWP and CVP pumping volume (cfs) to arrive at total salvage values. The total annual salvage for the action alternatives was compared to the total annual salvage for the No Action Alternative.

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